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A SURVEY OF POTENTIAL IMPACTS OF BOATING ACTIVITY ON ESTUARINE PRODUCTIVITY

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by:

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(This information is the result of reviewing literature from varying sources and is meant to indicate possible directions for further investigation rather than to draw any definite - or indefinite - conclusions concerning potential impacts.)

An increasing amount of attention is being directed towards the health of our living marine resources. Declining stocks of economically and/or ecologically important species of finfish and shellfish in recent years have generated a great deal of focused public scrutiny, unfocused legislation, high profile law suits and friction between competing user groups. Generally this culminates in attempts - usually successful - to fix the blame on (commercial) overfishing, power generation or loss of "critical" habitat. But, having been employed by or for commercial fishermen for the past fifteen years, I have yet to be convinced that their efforts are up to the task of severely depleting so many stocks so rapidly. In fact the total commercial fishing effort in the Mid-Atlantic region on the traditional "inshore" species has probably increased less than 10% in the last ten years. Likewise, installed electrical generating capacity hasn't increased significantly in this time. And while coastal development, generally considered to be the prime cause of habitat destruction, has been continuing, in recent years it has been carried out in an increasingly controlled and environmentally responsible manner.

But what has changed? In 1979 the total number of boats registered in New Jersey, including most motorized craft but excluding jet skies and the larger documented vessels, was 110,000. In 1989 this number had risen to 173,000, an increase of 57%. Quoting Dr. William Fox, who as the National Oceanographic and Atmospheric Administration's Assistant Administrator for Fisheries is the head fisheries manager for the federal government, "Over 70 percent of the U.S. commercial and recreational landings that provide over $30 billion to the U.S. economy are composed of species associated with estuaries at some time in their life history. Seventy percent of our production is dependent upon the preservation of nearshore habitat." (taken from a presentation by Dr. Fox to the National Fisheries Institute, April, 1991). These critical estuaries are the site of most of the boating activity in the Mid-Atlantic and are obviously on the receiving end of most of the growth in that activity.

Through contacts with marine researchers, environmentalists and resource managers it was found that, with the exception of a few narrowly defined areas of investigation, virtually no recent work has been done on the impact of boating activity on the estuarine environment. Some studies were completed in the 1960's and early 70's (when recreational boating was carried on at a level significantly less intensive than it is today, boats being smaller and with much less power), some questions were raised, and then the research community directed its attention elsewhere. But it seemed as if, at least with the levels of recreational boating use that have become common in water bodies such as New Jersey's coastal bays, there might very well be an impact of such activities on at least some of the less tolerant finfish or shellfish species.

With this in mind, a literature review was begun aimed at identifying negative impacts from sources that could be related to those that might be generated by boating. These impacts were grouped into three categories: direct physical stresses on aquatic organisms similar to those that might be caused by vessel operation (impacts by propeller leading edges or hull parts, propeller generated turbulence and shear forces, hull generated rotational forces), negative impacts on the physical environment similar to those that might be caused by vessel operation (increased thermal loading, increased turbidity, disruption of stratification) and biological effects of pollutants, particularly hydrocarbons, similar to boat engine emissions. While little or no work is available directly assessing the impacts of boat operation, enough has been done in related or similar areas to allow inferences to be drawn regarding whether or not an actual potential exists for such impacts.

DIRECT PHYSICAL STRESSES:

Some research has been carried out, primarily by the Corps of Engineers, on physical impacts to fish and invertebrates from commercial river traffic - barges and tow boats - and a significant amount has been done to assess the impact on aquatic organisms of passage through hydroelectric turbines or thermoelectric generating station cooling systems. Physical damage, principally occurring during passage through the circulating pumps, was reported as the major cause of entrainment mortality of aquatic organisms during normal power plant operation (Shubel and Marcy, 1978) and shearing and striking were determined to be the major causes of damage to fish passing through turbines (with significant damage - decapitation and losses of chunks of flesh - attributed to cavitation forces as well. Bell, 1974). However, other workers (Taylor and Kynard, 1985 and Cramer and Oligher, 1974) reported that cavitation in turbines was the chief cause of mortality of entrained organisms. (While the role of cavitation in turbine and pump induced injuries and mortality is poorly understood, there is general agreement that it is a factor).

The shear and rotational forces generated along the wetted surfaces of barge traffic on the upper Mississippi were reported to have caused damage to 20% to 50% of fish eggs in the area of passage (Holland, 1986). Propeller generated turbulence 17 meters behind a vessel pushing barges varied from 2,500 dynes/cm^2 with unloaded barges going upriver to 50,000 dynes/cm^2 with loaded barges going down river (Kilgore and Conley, 1987) and Morgan et al experimentally determined that shear stresses between 120 and 785 dynes/cm^2 for 1 to 20 minutes were lethal to 50% of eggs and larvae of striped bass and white perch (1976). In laboratory tests on paddlefish and carp, significant differences in mortality were seen in larvae exposed to low versus high levels of turbulence similar to those resulting from commercial river traffic (Pearson et al, 1989).

There isn't agreement on either the magnitude of the forces generated by particular types of vessel operation or pump and turbine impellers operated under different conditions. Nor is there a consensus on the magnitude of the forces required to cause a specific level of injury or death to particular organisms. There is general agreement, however, that the disturbances to the water column caused by vessels and by the impellers of large pumps and turbines may be responsible for injuring or killing aquatic organisms and that the eggs and larval stages of finfish and shellfish are much more susceptible to damage by these forces than juveniles and adults.

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IMPACTS ON THE PHYSICAL ENVIRONMENT:

Heat: To the extent that elevated temperatures may be a concern in an estuary under a particular set of conditions, added thermal input from any source could be significant. With an understanding of the intensity and distribution of boating activity in a particular estuary, it should be possible to model the effects of the resultant thermal inputs to determine under what conditions - if any - they could have any effect.

Turbidity: The deleterious effects of dredging induced turbidity on the estuarine environment are now commonly accepted and dredging projects are designed to minimize them. While adult finfish are capable of either avoiding or withstanding high levels of turbidity, eggs, larvae and juveniles can be severely impacted. Effects of increased turbidity include: smothering of sessile organisms, prolonged hatching time (Morgan, Raisin and Noe, 1983), reduction in growth, lessened feeding efficiency (Newcombe and MacDonald, 1991), impaired schooling ability (Pearson et al, 1989), and impaired growth of bottom vegetation due to lessened light penetration. While reported for only one species, herring larvae moved to higher levels of the water column as turbidity increased (Johnston and Wildish, 1982). Breitburg (1988) speculated that turbidity and other factors affecting feeding in the Chesapeake system might account for the difference between actual and predicted spawning success in striped bass while Morgan, Raisin and Noe reported that high turbidity levels could reduce larval survival in the same species by 57% (1983). Sediment loading and turbidity have long been recognized as significant factors in the successful hatching and development of salmonids.

Organic and inorganic sediments also play an important role in the movement and concentration of toxic materials in the estuarine environment.

Disruption of Stratification: Temperature and density (salinity) stratification during certain periods are characteristic of some estuaries. While it is possible that intense boating activity might disrupt such stratification, no descriptions of any other mechanisms capable of disrupting such stratification nor any effects of such a disruption were discovered.

ENGINE EMISSIONS:

The effects of hydrocarbons and heavy metals on and their movements through the marine environment have generated volumes of material that need not be surveyed here. However, areas with particular relevance to possible boating impacts include the concentration of these substances through adsorption onto suspended particles and in the flocculent layers of bottom sediments; the persistence of these substances in the marine environment (Burns and Saliot, 1986); and their contributions to forming microlayers at the air/water interface. Von Westerhagen et al (1987) reported that surface microlayer materials significantly affected development and survival of marine fish eggs and discussed the high susceptibility of thin-shelled pelagic eggs to petroleum hydrocarbon-derived pollution of natural waters. In Puget Sound it was demonstrated that exposure to surface microlayer samples collected from urban bay sites resulted in increased chromosomal aberrations in developing sole embryos and reduced hatching rates of sole eggs. These effects were associated with high concentrations of contaminants, including hydrocarbons and heavy metals.

From the foregoing, it is obvious that, given a high enough level of boating activity, there could be some negative effects on the estuarine environment or to fish stocks, particularly at the

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more susceptible early life stages. From here, then, we moved to a review of the available information on boating usage (fortunately, a number of data collection efforts - including the EPA initiative that has resulted in this workshop - were underway or had been recently completed and will provide a reasonably solid basis for future work).

BOATING USE LEVELS:

Going back to the early sixties (English, McDermott and Henderson, 1963), "extreme critical" boating use intensity - one that would have a significant toxic effect on fish life - was determined to be (converting their figures) at a level that used 18 gallons of fuel per acre-foot of lake volume per year. Eleven years later (Breidenback, 1974) "Saturation Boating Use" was determined for 5,100 acre Lake Geneva, Wisconsin for 600 boats with 9,000 total horsepower (300 boats with 5 hp engines used for trolling, 150 with 40 hp for water skiing and 150 with 10 hp for "boating"). When converted, their figures yielded a 15 gallon per acre-foot per year fuel use (assuming a 5 month boating season).

These can be contrasted with the current situation in Barnegat Bay, New Jersey. Barnegat Bay is fairly typical of estuaries in the Mid-Atlantic region. Having a total area of 47,000 acres, an average depth of 4.5 feet, a maximum depth of about 13 feet and 44% of its area covered by less than three feet of water, it is the site of intensive recreational boating activity for four or five months each year. There are 11,500 slips in marinas, an unknown number at private residences, dry storage for 7500 boats and 45 boat launching ramps in Barnegat Bay. Thirty percent of New Jersey's recreational boating takes place on this bay (Rogers, Golden and Halpern, 1990). Using recently derived figures for recreational boating fuel use in New Jersey commissioned by the U.S. Fish and Wildlife Service (Price Waterhouse, 1992), it can be estimated that 10,344,000 gallons of fuel was used in recreational boating on Barnegat Bay in 1990 (30% of New Jersey's total recreational boating fuel consumption of 34,481,000 gallons) This represents a usage level of 50 gallons per acre-foot per year and hasn't generated any discernible interest as being "out of the ordinary" or in any way exceptional.

What were once considered to be "worst case" levels of boating activity now appear to be regularly and significantly exceeded during normal recreational use of coastal waters.

DIRECT PHYSICAL IMPACTS:

Looking at the potential for direct physical impacts of boating activity on estuarine organisms it was assumed that the propeller of a boat in motion would impact on a volume of water - and the finfish and shellfish eggs, larvae and juveniles in it not capable of escape - equivalent to the area swept by the prop moving through the water at the speed of the vessel (while this is probably underestimating the volume - and organisms - impacted considerably it is adequate for an initial approximation). A propeller 14 inches in diameter sweeps an area of approximately one square foot. At 30 miles an hour it would pass through and directly affect 3.6 acre-feet of water every hour. For comparison, an "average" base load generating station uses 150,000 cubic feet of water a minute - sixty boats worth - for condenser cooling. If all of the 19,000 boats in commercial storage (marina slip and rack) on Barnegat Bay were single screw craft capable of 30 miles an hour, a volume of water equivalent to the entire volume of the bay - 211,000 acre feet - would be completely swept by their propellers in only 3 hours of combined operation.

While not quantifiable at this time, it is hard to imagine that the impacts on affected estuarine organisms - particularly the more fragile eggs and larvae - of the propeller driving a boat at what are now accepted as normal cruising speeds aren't dramatic. They might well be of the same order of magnitude as those of the pumps and turbines in thermoelectric or hydroelectric plants.

EMISSIONS:

Because of a lack of accessible performance data (marine engines are for the most part unregulated) the potential impact of marine engine emissions is one that is hard to get a direct handle on, at least for modern engines. Using the Price Waterhouse recreational fuel use figures previously referred to and projecting the levels of emissions reported by Breidenback in 1974 gives a dated (and we hope inflated, based on the improved performance of today's motors) measure of these emissions. Returning to Barnegat Bay, estimating that 80% of the total recreational boating fuel is used by outboard motors, and applying Breidenback's conclusion that the "average" pre-1974 motor will contribute 2.5% of its fuel to the water during most of the time it is in use would result in releases to the Bay of almost 500 tons annually. Even assuming a significant improvement in outboard engine efficiency and emission control since 1974 and a corresponding reduction in the release of condensable material ("...found to contain parrafinic, olefinic and aromatic hydrocarbons, as well as small amounts of phenols and carbonyl compounds." Breidenback, 1974) to only 1% of the total fuel input, the yearly release is still 200 tons for Barnegat Bay and 600 tons for the entire state.

POSSIBLE OBM INPUTS INTO COASTAL WATERS (and how they were estimated):

- 11,000,000 galons = 55,000,000 pounds = 25,000 tons/yr recreational fuel use in Barnegat Bay
- 34,000,000 galons = 170,000,000 pounds = 77,000 tons/yr recreational fuel use in N.J. Waters
- 0.80 (Percentage of outboard motors in Barnegat Bay) x 25,000 tons fuel used = 20,000 tons OBM fuel used/yr in Barnegat Bay
- 0.80 (Percentage of outboard motors in New Jersey) x 77,000 tons fuel used = 60,000 tons OBM fuel used/yr in New Jersey waters
- 0.01 (Total hydrocarbon contribution reduced from Breidenbeck*) x 20,000 tons = 200 tons hydrocarbons into Barnegat Bay annually
- 0.01 (Total hydrocarbon contribution reduced from Breidenbeck) x 60,000 tons = 600 tons hydrocarbons from recreational boating into New Jersey waters annually

*The total amount of condensable material which can reasonably be expected to be condensed in a boating situation varied *from about 1.5 to 7 percent of the fuel used.*"(pg 1. Section 1. Breidenback, 1974)

Assuming New Jersey has 1/50th of the total U.S. outboard boating activity (a conservative estimate given the length of the N.J. coastline and the abbreviated boating season here), then annual U.S. hydrocarbon inputs from OBMs could be 30,000 tons - mostly concentrated in the estuaries and nearshore waters. Total inputs of all petroleum products into the world ocean annually have been estimated to be from 1.7 to 8.8 million metric tons. The estimate for the total (worldwide) from urban runoff in 1985 was 40,000 tons and from industrial wastes was 200,000 tons. "While inputs from pleasure craft may be locally significant, we believe that the total amount of this input would not be on the same scale with the other inputs."(Steering Committee ..., 1985). Since 1981 total oil inputs from shipping into the world's oceans declined 60% to 568,000 tons (Marine Pollution Bulletin, 1990).

While these estimates (and I hesitate to refer to them even with the level of accuracy that "estimate" implies) are nowhere near conclusive, they are an indication that, in spite of the Academy's belief to the contrary, outboard motor operation could be a major source of petroleum products released into the world's oceans, with effects focused on our own coastal waters.

TURBIDITY:

As reported by Yousef (1974), in water depths of 15 feet the operation of a 50 horsepower outboard would re suspend bottom sediments in a lake in Florida. Isolating turbidity attributable to boating activity - and its impacts - from that occurring normally or resulting from other anthropogenic activities would be difficult. However, it seems obvious that in shallow water bodies exposed to high natural inputs of silt, boating activity could play a large part in re suspending sediments and, particularly with the finest fractions, keeping them in suspension. Along with the direct contribution to increased turbidity, this could also contribute indirectly through making nutrients more readily available to the phytoplankton (Yousef et al, 1980). The role of boat traffic in increasing turbidity - and decreasing the survival of bottom vegetation - has received a great deal of attention in the United Kingdom (Garrad and Hay, 1987, Liddle, 1980 and others).

OTHER IMPACTS:

There are a several other potential negative impacts resulting from boating activities - propeller bottom scouring, leaching of toxics from bottom paints, spills during fueling operations, waste releases, etc. - that are at this point being considered and evaluated by the research community and aren't covered here.

The potential impacts that have been surveyed, however, have been ignored for the past twenty years. They are - or should be - of particular concern because any of them could be playing a significant role in the decline of one or several species that are or have been important to the inshore recreational and commercial fisheries in the Mid-Atlantic region.

The bay anchovy *(Anchoa mitchilli)*, one of the primary forage fish in these waters, is an estuarine spawner from April to September that lays neutral density eggs. After hatching, the larvae migrate to the lower salinity, shallower and near-surface waters where they remain until winter approaches (Grosslem and Azarovit, 1986, Vougliotois et al, 1987). Declines in the abundance of bay anchovies is part of the impetus (declining weakfish stocks is the other) to force the construction of cooling towers at a nuclear power plant on the Delaware River. Bluefish *(Pomatomus saltatrix)* support an important commercial fishery and the largest segment of the recreational fishing industry in the Mid-Atlantic. Ocean spawners, the juvenile fish move into the estuaries in the spring and remain there until the waters begin to cool in the fall. Striped bass *(Morone saxatalis)* are important commercially and recreationally. Severe population declines attributed to lack of hatching success and/or larval survival in recent years have forced the almost complete closure of the fishery. Supposedly based on a single successful year-class, the striped bass fishery has been reopened but severely restricted for the past two years. Striped bass are estuarine spawners in the early spring, the juveniles moving into the ocean in the fall. Weakfish *(Cynoscion regalis)*, summer flounder *(Paralichthys dentatus)*, American oysters *(Crassostree virginica)* and hard clams *(Mercenaria mercenaria)* as well are all dependent on the Mid-Atlantic estuaries for spawning, larval development and/or maturation during the peak of the recreational boating season and all are experiencing serious stock declines.

These species would all be in a position to suffer most acutely any negative effects of boat operation. They are in the estuaries during the peak boating period; they are there in forms - eggs, larvae or juveniles - least able to avoid or withstand physical or chemical challenges; they are generally found in the upper water levels that would receive the greatest impact of boating activity, possibly in prolonged contact with toxic substances concentrated in water surface microlayers or on constantly re suspended solids; and they are often being stressed by low oxygen levels and/or high water temperatures.

Considering the importance of maintaining the health of our inshore waters, the intensive and increasing use of these waters by recreational boaters, the increasing demands placed upon them by competing user groups, and the growing public attention directed towards the misuse - perceived or actual - of any public resource, further examination of these areas that I have briefly touched on is definitely warranted. Solely on the basis of the volume of water that they directly and violently disturb, it would seem that boating activities should receive a partial share of the scrutiny that other coastal activities must endure, at least until reasonable estimates concerning what - if any - impacts they are responsible for can be made. In New Jersey alone the unburned residues, combustion products and generated heat from 30 million gallons of fuel are injected into our highly productive estuarine waters each year, generally at a time that is most critical to the delicate eggs, larvae and juvenile life stages of many of our important species. The impacts - if any - of this demand investigation as well.

Penalties and restrictions levied against other users of our estuarine resources for the supposed impacts of their operations on our fishery resources amount to billions of dollars each year. If these penalties and restrictions are misdirected and ineffective (and the continuing declines in many of our fisheries seem to be arguing strongly that they might be), then increasing them will be of no benefit. At the same time, continuing to ignore the effects of recreational boating - probably cumulative and possibly devastating - and allowing its continuing unfettered growth could be exacerbating a situation which could already be far beyond critical.

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English, J., E.W. Surber and G.N. McDermott, #63, 1963, **Pollutional Effects of Outboard Motor Exhausts-Field Studies**, Journal of Water Pollution Control Federation, 35, 1121-1132.• Ditto laboratory work above using small motors. Does mention cumulative build-up of emissions and reports an off-flavor in fish when the fuel consumed reached 10.8 gallons per million gallons of water and "severe fish flesh tainting" at 18 gallons per million gallons.

Fogt, J., **Experts: Nets Cause Less Damage To Environment Than Propellers**, #26, Palm Beach Post, April 8, 1981

Garrad, P.N. and R.D. Hey, #23, 1987, **Boat Traffic, Sediment Resuspension and Turbidity in a Broadland River**, Journal of Hydrology, 95.• U.K. study showed that decreasing boat speed from 7 mph to 5 mph could significantly reduce the resuspension of low density bottom sediments. Diurnal observations showed peaks in sediment loading correlating with peaks in river traffic. Suggests that boat traffic be considered as a source of turbidity along with algae.

Ginn, T.C., G.V. Poje and J.M. O'Connor, 1977, **Survival of Planktonic Organisms Following Passage Through a Simulated Power Plant Condenser Tube**, in proceedings of the Fourth National Workshop on Entrainment and Impingement - Loren D. Jensen editor).• Report on a full-scale condenser tube simulator designed to assess the pressure, flow, temperature and biocide characteristics of power plant cooling water systems. No velocity attributable mortalities were seen in *Chaoborus* (midge) or carp larvae at 0.91 to 3.08 m/sec. Carp larvae showed no sensitivity to the sub atmospheric pressures they were exposed to. Cited studies "indicating "70% - 80% mortalities of entrained organisms due to mechanical stress" (Marcy 1971, Carpenter *et al* 1974).

Gregg, R.E. and E.P. Bergersen, #50, 1980, ***Mysis relicta*: Effects of Turbidity and Turbulence on Short-Term Survival**, 1980, Transactions of the American Fisheries Society, 119.• The possum shrimp *Mysis relicta* (described as "very fragile" and never having been reported in flowing waters) is similar in body shape and size to striped bass and white perch larvae which Morgan et al showed to be negatively affected by turbulence. In this work there were not negative effects demonstrated by turbidity at the levels tested but turbulence (caused by air release into the containers and measured by the re oxygenation or diffusion constant *K*) caused "...a highly significant increase in mortality...." which was attributed to abrasion from the container walls, shear stresses caused by turbulence and exhaustion.

Grosslem, M.D. and T.R. Azarovit, #2, **Fish Distribution**, Marine Ecosystem Analysis Program, New York Sea Grant.• Natural history of important species, range, distribution, seasonality, etc. Included are sections on fluke, sea bass, striped bass, bluefish, hard clams, oysters, winter flounder, bay anchovies, weakfish.

Gucinski, H., 1982, **Sediment Suspension and Resuspension from Small Craft Induced Turbulence**, USEPA Contract EPA-78-D-X0426

Hansen, W.G., G. Bitton, J L. Fox and P.L. Brezonik, 1977, **Hydrocarbon Status in Florida Real Estate Canals**, Marine Pollution Bulletin, 8-3.

Hardy, J., S. Kiesser, L. Antrim, A. Stubin, R. Kocan and J. Strand, #38. 1987, **The Sea-surface Microlayer of Puget Sound: Part 1. Toxic Effects on Fish Eggs and Larvae.** Marine Environmental Research, 0141-1136.

Hardy, J.T. 1987, #40, **Anthropogenic Alteration of the Sea Surface**, Marine Environmental Research, 0141-1136.

Hare, C.T., and K.J. Springer, 1973, **Exhaust Emissions from Uncontrolled Vehicles, Part 2: Outboard Motors**, Contract EPA - 7- -108 SwRI-AR-850, APTD - 1491.

Haven, F.H. and T.C. Ginn, 1977, **A Mathematical Model of the Interactions of an Aquatic Ecosystem and a Thermal Power Station Cooling System**, in proceedings of the Fourth National Workshop on Entrainment and Impingement - Loren D Jensen editor).• Contains a section on "Fluid-Induced Stress" which reports vastly divergent entrainment mortality values ranging from 2.9% (Hudson River Zooplankton) to 99.7%.

Heinle, D.R., 1976, **Effects of Passage Through Power Plant Cooling Systems on Estuarine Copepods**, Environmental Pollution, 11-39. (from Haven and Ginn above)

Hershner, C., #16, 1986, **Marina Sitings From The Scientific Advisor's Viewpoint**, Chesapeake Bay Research Conference, Williamsburg, VA (March 20, 21).

Hilton, J. and Phillips, G.L. 1982, **The Effect of Boat Activity on Turbidity in a Shallow Broadland River**, Journal of Applied Ecology 19, 143-150

Holland, L., #29, **Effects of Barge Traffic on Distribution and Survival of Icthyoplankton and Small Fishes on the Upper Mississippi River**, Transactions of the American Fisheries Society, vol. 115, 1986. • Measured significant damage to eggs after barge passage (no effect seen on juvenile fish). Impact was greater after passage by loaded barges moving downstream (20% vs. 50% damaged eggs)

Holland, L E. and J.R. Sylvester, #27, 1983, **Distribution of Larval Fishes Related to Potential Navigation Impacts on the Upper Mississippi River, Pool 7**, Transactions of the American Fisheries Society, 112.

Jackivicz, T. and L. Kuzminski, #38, **A Review of Outboard Motor Effects on the Aquatic Environment**, Journal of the Water Pollution Control Federation, Vol. 45, p. 1759 - 1770, 1973.• Reported that an untuned outboard motor engine running at low speed (1000 rpm) could release 30% of its fuel to the receiving waters while at higher speeds (3000 rpm) the release was less than 3%. Also mentioned S.2096 (*Congressional Record* June 18, 1971) requiring best available technology for two-cycle engines in water craft. Mentions other components of outboard exhausts as well as reasonable reference section

Jackivicz, T P. and L.N Kuzminski, #3, 1973, **The Effects of the Interaction of Outboard Motors with the Aquatic Environment: A Review**, Environmental Research, 6.• Early mention of thin (monomolecular) oil film. Reported a negative effect of outboard motor exhausts on the taste of fish flesh. Some toxicity work reported.

Johnson, T, #34, 1991, **Auto Industry, Jersey Tussle on Smog Policy**, The (Newark) Star Ledger (November 25, 1991).

Johnson, D.D. and D.J. Wildish, #61, 1982, **Effect of Suspended Sediment on Feeding by Larval Herring *(Clupea harengus harengus* L.)**, Bulletin of Environmental Contamination and Toxicology, 29, 261-267.• Lower levels of suspended sediments (4 and 8 mg dry sediment/l) had no effect on larval feeding. However, higher level (20 mg/l) caused a significant reduction in feeding success. With increased suspended sediment levels, the concentration of larval herring moved towards the upper layers of the water column.

Killgore, K. A and K. Conley, #31, **Effects of Turbulence on Yolk Sac Larvae of Paddlefish**, Transactions of the American Fisheries Society, vol. 116, 1987.

King, R.G., 1977, **Entrainment of Missouri River Fish Larvae through Fort Calhoun Station**, in proceedings of the Fourth National Workshop on Entrainment and Impingement - Loren D. Jensen editor).• Attributes a high larval fish mortality on the intake side of the power plant to net- and naturally induced mortality ("including high current velocities, turbulent flow, and heavy detritus, silt, and sand loads"). Current velocities in the Missouri River in the area were reported as "normally" exceeding 100 cm/second.

Kiorboe, T., F. Mohelenberg and O. Nohr, #22, 1981, **Effect of Suspended Bottom Material on Growth and Energetics in *Mytilus edulis***. Marine Biology, 61.

Koopleman, L.E., 1982, #5, **Long Island Non point Source Management Handbook**. Long Island Regional Planning Board.• The section in hand is titled "Boat Pollution" and mentions oil products but states "The most significant impact from boating activities is the discharge of untreated and partially treated sanitary wastes.

Lawler, Matusky & Skelly Engineers, #11 1989, **Intake Technologies: Research Status**, EPRI

Liddle, M.J. and H.R.A. Scorgie, #4, 1980, **The Effects of Recreation on Freshwater Plants and Animals: A Review**, Biological Conservation, 17.• British work describes the negative impacts of recreational boating including propeller damage (minimal mention), turbulence and turbidity. A more extensive treatment of outboard motor caused pollution.

Lifton W.S and J F. Storr, 1977, **The Effect of Environmental Variables on Fish Impingement**, in proceedings of the Fourth National Workshop on Entrainment and Impingement - Loren D. Jensen editor) • Reports on operating characteristics of several power plants:

Marcy, B.C., 1974, **Vulnerability and Survival of Young Connecticut River Fish Entrained at a Nuclear Power Plant**, in proceedings of the Second Workshop on Entrainment and Intake Screening (EPRI Project rp-49, Report #15).• At a generating station on the Connecticut River (683 cubic feet per second at full load) mechanical, biocide and thermal mortalities were estimated. Mortality due to mechanical damage ranged from 72% to 87% (consistantly 71% to 72% with mostly <15 mm fish except for one sample when larger fish - 20 to 40 mm total length - were present. Most of the fish entrained were post yolk-sac stages and 97.6 were more fragile Clupeids. Good ref. list on mechanical damage at power plants.

Marcy, B.C., #56, 1971, **Survival of Young Fish in the Discharge Canal of a Nuclear Power Plant**, Journal Fisheries Research Board of Canada, 28, #7,1057-1060

Mason, C.F. and R.J. Bryant, 1975, **Changes in the Ecology of the Norfolk Broads**, Freshwater Biology, 5, 257-270

McMahon, P.J.T., #17, 1989, **The Impact of Marinas on Water Quality**, Water Science Technology, 21-2.

Miller, B. and B. Payne, #28, **The Use of Quantitative Data on Freshwater Mussels to Assess the Environmental Impacts of Commercial Navigation Traffic on Waterways of the United States**, Association Internationale Permenanente Des Congres De Navigation. vol. 73, Bulletin 1991.

Miller, A.C., K.J. Killgore and B.S. Payne, 1987, #21, **Bibliography of Effects of Commercial Navigation Traffic in Large Waterways**, Department of the Army Waterways Experiment Station Misc. Paper E-87-1

Missouri River in Nebraska (Doctoral Thesis, Univ. of Nevada, Lincoln).• Cited in King (1977) as reporting a linear relationship between percentage mortality and current velocity.

Morgan, E.J. and R.H. Lincoln, #14, **Duty Cycle for Recreational Marine Engines (901596)**, SAE Technical Paper Series, International Off-Highway & Power plant Congress and Exposition, September, 1990.• Industry technical report details outboard and other marine engine sales by size (horsepower) and recommends an "average" usage factor for various motors.

Morgan, R.P., V. Raisin and L. Noe, **Sediment Effects on Eggs and Larvae of Striped Bass and White Perch**, Transactions of the American Fisheries Society, vol. 112, 1983.

Morgan, R., R. Ulanowicz, V. Raisin, L. Noe and G. Gray, #30, **Effects of Shear on Eggs and Larvae of Striped Bass and White Perch**, Transactions of the American Fisheries Society, vol. 106, 1976.

Morgan, R.P., R.E. Vlanowicz, V.J. Raisin L.A. Noe and G.B. Gray, 1973, **Effects of Water Movement on Eggs and Larvae of Striped Bass and White Perch**, Natural Resources Institute, Chesapeake Biological Laboratory, University of Maryland, NRI Ref. # 73-111.

Morgan, R.P, V.J. Raisin Jr. and L.A Noe, #49, 1983, **Sediment Effects on Eggs and Larvae of Striped Bass and White Perch**, Transactions of the American Fisheries Society, 112.•In laboratory showed no effects on hatching or larval survival but did demonstrate development delays in eggs of both species.

Moser, F., B. Ruppel, R. Scro & H. Boettcher, #9, **An Investigation of Two Marinas as Sources of Pollution in Barnegat Bay, N.J.**, - *Unpublished report prepared for NJDEP, Division of Science and Research.* • 12,000 marina slips on Barnegat Bay; Addresses Bacteriological and Metals contamination on the bay but does mention resuspension of metals **in marinas** and lead through the exhaust emissions of outboard motors.

Moss, B. #58, 1977, **Conservation Problems in the Norfolk Broads and Rivers of East Anglia, England - Phytoplankton, Boats and the Causes of Turbidity**, Biological Conservation, 12, 95-114. • Reports that boating traffic had no effect in increased turbidity in the rivers in question, rather that increased nutrient loading was responsible (see Yousef et al, 1980).

Muir, J.F., 1959, **Passage of Young Fish Through Turbines**, Proceedings of the American Society of Civil Engineers, 85, 23-46

Murphy, K.J. and J.W. Eaton, 1983, **Effects of Pleasure Boat Traffic on Macrophyte Growth in Canals**, Journal of Applied Ecology, 20, 713-729.

Newcombe, C.P and D.D. MacDonald, #25, 1991, **Effects of Suspended Sediments on Aquatic Ecosystems**, The American Journal of Fisheries Management, 11, 72-81. Reviews lethal and sub-lethal effects of suspended sediments on salmonids and invertebrates - *from a trout/salmon reproductive (egg-hatching, etc.) perspective primarily.*

Nielsen, L.A., R.J. Sheehan and D.J. Orth, 1985, **Impacts of Navigation on Riverine Fish Production in the United States**, Foldkie Archives Hydrobiologie, 33, 277-294.

NJDEP, #10, 1991, **Summary of Barnegat Bay Watershed Planning Process**, No mention of outboard motor emissions, other possible deletorious impacts.

NJDEPE, 1992, **A Watershed Management Plan for Barnegat Bay - A Working Draft**, Focuses on land and water use controls in a typical planning document. Boating controls focus on traffic, noise, marina "spillage", vegetation damage and sewage problems.

NOAA/NMFS, #249, 1991, **Status of the Fishery Resources off the Northeastern United States for 1990**, NOAA Tech. Memo. NMFS-F/NEC-81. • Landings statistics, etc. for 1990 and ten years prior for all commercially and recreationally important non-inshore(fluke are included, weakfish aren't?) species.

O'Connor, J.M. and S.A. Schaffer, #57, 1977, **The Effects of Sampling Gear on the Survival of Striped Bass Icthyoplankton**, Chesapeake Scientist, 18,3, 312-315. • Immediate and 72 hour survival of eggs, yolk sac larvae and 14 day old striped bass larvae released into a plankton net in an experimental flume with velocities of 0.5, 1.5 and 3.0 fps. Immediate and latent mortalities were velocity dependent with yolk sac larvae being most sensitive with post yolk sac larvae intermediate and eggs most resistant. Mortalities ranged from 100% (all stages at 3.0 fps) to 20% (eggs at 0.5 and 1.5 fps).

Payne, B.S., K.J. Killgore and A.C. Miller, #45, 1990, **Mortality of Yolk-Sac Larvae of Paddlefish Entrained in High-Velocity Water Currents**, *Journal of Mississippi Academy of Sciences, vol. 35.* • *Describes immediate and delayed mortalities of* paddlefish larvae released into water currents with velocities of from 1.5 to 4.2 meters per second. Percent mortality ranged from 6% to 68% after 24 hours and appeared to increase exponentially with current velocity. The exposure was acute, amounting to less than one second.

Pearson, D, K. Killgore, B. Payne and A. Miller, #18, **Environmental Effects of Navigation Traffic: Studies on Fish Eggs and Larvae**, Department of the Army Environmental Impact Research Program Technical Report EL - 89 - 15, 1989. • Along with bibliography/literature review, reports on laboratory work assessing the impacts of water velocity and turbulence on the survival of paddlefish and carp (common and grass) larvae. Significant mortalities were observed at levels that were equivalent to those created by commercial river traffic.

Poje, G.V., S.A. Riordan and J.M. O'Connor, 1981, **Power Plant Entrainment Simulation Using A Condenser Tube Simulator (Final Report)**, U.S.N.R.C. (Division of Health, Siting and Waste Management). NUREG/CR-2091. • In a condenser tube simulator demonstrated no additional (with delta T and biocides) mortality of six estuarine organisms (striped bass eggs and larvae, carp larvae, daphnia, dipteran larvae, mysid shrimp and two amphipods) attributable to physical stress of condenser tube passage.

Price Waterhouse, #65, 1992, **Preliminary Report From The National Recreational Boating Survey - New Jersey Executive Summary** (done under contract for the U.S. Fish and Wildlife Service and currently under review by that agency). This is a national survey of recreational boating fuel use accomplished on a state - by - state basis. While it doesn't differentiate between fresh and saltwater use, it does present a breakdown according to vessel size and type, fuel type, and engine type. According to the FWS project leader, the full report should be released in November.

Rogers, Golden and Halpern, Inc. #70, 1990, **Profile of the Barnegat Bay**, (prepared for the Barnegat Bay Study Group).

Sammut, M. and G. Nickless, #41, 1978, **Petroleum Hydrocarbons from Marine Sediments and Animals from the Island of Malta**, Environmental Pollution, 16.

Schubel, J.R. and B.C. Marcy Jr., #47, 1978, **Power Plant Entrainment: A biological Assessment**, Academic Press.• (Copy of Chapter 4 - "Effects and Impacts of Physical Stress on Entrained Organisms") Covers different forces involved in entrainment as well as particularly susceptible (or studied) organisms Good literature review as well as rudimentary analysis of forces (acceleration, shear, abrasion/collision) involved.

Schuster et al, 1974, **Effects of Exhausts from Two Cycle Outboard Engines**, EPA - 670/2 - 74 - 063. (Environmental Engineering Dept. at Renssalaer Poly.)

Steering Committee for the Petroleum in the Marine Environment Update, #43, **Oil In The Sea**, National Academy Press, 1985.• Details major natural and man-made sources - worldwide - of oil pollutants ending up in the worlds oceans Quantities range from 0.005 metric tons annually (from ocean dumping) to 1.5 metric tons annually (tanker operations and municipal wastes).

Stewart, R. and H. Howard, 1968, **Water Pollution by Outboard Motors**, The Conservationist, 6, 6.

Stokesbury, K.D.E. and M.J. Dadwell, #32, 1991, **Mortality of Juvenile Clupeids during Passage through a Tidal, Low-Head Hydroelectric Turbine at Annapolis Royal, Nova Scotia**. North American Journal of Fisheries Management, 11:49-154.

Stone & Webster Engineering Corporation 1990, #13 (synopsis), **Fish Protection Systems for Hydro Plants**, EPRI (project RP2694-1)

Sullivan, C.W., #12 (synopsis), **Turbine Related Fish Mortality: Review and Evaluation of Studies**, EPRI (project RP2694-4).

Taylor, R.E. and B. Kynard, #48, 1985, **Mortality of Juvenile American Shad and Blueback Herring Passed through a Low-Head Kaplan Hydroelectric Turbine**, Transactions of the American Fisheries Society, 114.• "..cavitation is thought to be the most important source of mortality to juvenile fish passed through Kaplan turbines."

USEPA, **Nonroad Engine and Vehicle Emission Study -- Report** (EPA - 21A - 2001), #20, Certification Division, Office of Mobile Sources, November, 1991.• Lots of information on numbers of boats in use, average usage, air pollutants, average fuel use, etc.

Vernam, T. and R. Connell, #44, 1991, **Audit of Impacts Resulting from Marina Activities on the Estuarine Environment along the New Jersey Coast** (DRAFT), Submitted to Environmental Auditor.

Von Westerhagen, H., M Landolt, R. Kocan G. Furstenberg, D. Janssen and K. Kremling, #33, 1987, **Toxicity of Sea Surface Microlayer: Effects on Herring and Turbot Embryos**, Marine Environ. Research, 0141-1136.

Vouglitois, J.J., Able, K.W., Kurtz, R.J. and K.A. Tighe, #53, 1987, **Life History and Population Dynamics of the Bay Anchovy in New Jersey**, Transactions of the American Fisheries Society, 116.• Centers mostly on Barnegat Bay. Most spawning during May to August. Barnegat trawl surveys reported bay anchovy eggs accounted for up to 98% of the annual egg catch and 56% of the annual larval catch "The offshore and southerly migrations of the bay anchovy in the northern part of its range therefore may represent a substantial export of productivity from the estuary to the offshore environment as has been suggested for other species in other areas."

Von Gunten, G., #60, 1961, **Fish Passage Through Hydraulic Turbines**. Journal Hydraulics Division., Proceedings American Society of Civil Engineers, 87 (HY3), 59-72.• It was possible to differentiate between mechanical injuries and pressure damage in recovered fingerlings. Highest mortalities were seen when turbines were operating at low efficiencies and through cavitating conditions. "Exposure to an area of vaporization and cavitation causes death."

Wade, T.L. and J.G. Quinn, #39, 1980, **Incorporation, Distribution and Fate of Saturated Petroleum Hydrocarbons in Sediments from a Controlled Marine Ecosystem**, Marine Environmental Research, 0141-1136/80/0003-0015.

Wang, J.C. and R.J. Kernehan, #1, **Fishes of the Delaware Estuaries**, EA Communications.• A description of the larval forms of the important Delaware estuarine species.

Yousef, Y.A., #64, 1974. **Assessing Effects on Water Quality by Boating Activity**, U.S.E.P.A., EPA Tech. Serv., EPA-670/2-74-072.• Study done on three Florida lakes addressing impacts of boat use on turbidity (and fertilization). Reported bottom disturbances by 50 horsepower outboard motor at up to 15 feet. Also reported that boating could prevent stratification, contribute to spread of macrophytes that can reproduce vegetatively (chopping then current etc. dispersal). Has good numbers on earlier motor sales. "There has been growing concern to those interested in the preservation of our natural resources over the possibility that outboard engined boats could be detrimental to our lakes and water bodies."

Yousef Y.A., W.M. McClellon and H.H. Zebuth, #59, 1980, **Changes in Phosphorous Concentrations Due to Mixing by Motorboats in Shallow Lakes**, Water Research, 14, 841-852.• Three lakes served as sites for outboard motor operations (28 to 165 horsepower). Boat operation caused increased turbidity and increased nutrient loading (due to resuspension of nutrient rich sediments). Results were significant in the shallower two lakes (average depth of 1.8 and 2.3 meters) but inconclusive for the deeper lake (4.0 meters). "Widespread interest in the results has developed both from citizens groups and governmental agencies. These interests are applicable to estuarine as well as fresh waters."